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SCIENCE GOALS AND PAYLOADS FOR COMMON PROBE MISSIONS TO VENUS AND THE GIANT PLANETS

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Science Justification for Planet Entry Probes

"Comparative planetology of well-mixed atmospheres of the outer planets is key to the origin and evolution of the Solar System, and, by extension, extrasolar systems."

S.K. Atreya, et al. "Multiprobe exploration of the giant planets – Shallow probes", Proceedings of the 3rd International Planetary Probes Workshop, Anavyssos, Greece, 2005.

There is only one Rosetta Stone in the Solar System; it's in the British Museum. We cannot understand the inner planets by simply studying the Earth, nor can we apprehend the giants by examining only Jupiter. Despite the stunning successes of previous probes to Venus and the Galileo probe to Jupiter, our knowledge of the atmospheres of even these two planets remains tantalizingly incomplete. <u>We must therefore return to Venus and consider the challenge of exploring all of the outer planets</u> with a family of identical probes, a project that could commemorate the vision of multiple worlds championed by Giordano Bruno."*

T. Owen "Atmospheric Probes: Needs and Probspects," Proceedings of the 1st International Planetary Probes Workshop, Lisbon, 2003.

* *A.A. Martinez "*Giordano Bruno and the heresy of many worlds**,"** Annals of Science, Vol. 73, p345-37, 2016

Remote Sensing

Remote sensing has made profound contributions to current understanding of the solar system.

However, remote sensing:

- <u>Cannot</u> provide noble gas abundances and isotope ratios
- <u>Cannot</u> provide abundances of many condensable species. For example, presence of sulfur strongly suspected on Jupiter as H_2S. Only from Galileo probe was this gas detected.
- Is of limited usefulness in determining thermal structure, radiative energy balance, cloud location, composition, and microphysics, and dynamics (deep winds, waves, tides, etc.).

NASA 2018 Strategic Plan

STRATEGIC GOAL 1: EXPAND HUMAN KNOWLEDGE THROUGH NEW SCIENTIFIC DISCOVERIES

STRATEGIC OBJECTIVE 1.1: Understand the Sun, Earth, Solar System, and Universe.

> "Conduct scientific studies of the Earth and Sun from space, return data and samples from other bodies in the solar system, …"

The success criteria for SMD are progress in answering fundamental science questions, <u>implementing the decadal survey priorities</u>, etc.

https://www.nasa.gov/sites/default/files/atoms/files/nasa_2018_strategic_plan.pdf

Vision and Voyages: 2013-2022 Planetary Science Decadal Survey

Three overarching themes

- Building New Worlds - Understanding solar system beginnings
- Planetary Habitats - Searching for the requirements for life
- Workings of Solar Systems - Revealing planetary processes through time

https://solarsystem.nasa.gov/docs/131171.pdf

Giant Planets

The scientific objectives for probe exploration of the giant planets derive directly from the Planetary Science goals in the 2014 NASA Science Plan to

- Explore and observe the objects in the Solar System to understand how they formed and evolve
- Advance the understanding of how the chemical and physical processes in our Solar System operate, interact and evolve, and
- Improve our understanding of the origin and evolution of life on Earth to guide our search for life elsewhere.

https://www.nasa.gov/sites/default/files/files/2014_NASA_Strategic_Plan.pdf

Giant Planet Science Objective

Decadal mission studies – Saturn Probe

Tier-1:

1. Determine **noble gas abundances & isotopic ratios** in Saturn's atmosphere.
2. Determine **atmospheric structure** (temperature & pressure vs height) at probe descent location.

Tier-2:

3. Determine **vertical profile of zonal winds** as function of depth at probe descent location(s).
4. Determine **location, density, and composition of clouds** as function of depth in atmosphere.
5. Determine variability of atmospheric structure and presence of clouds *in two locations*.
6. Determine **vertical water abundance profile** at probe descent location(s).
7. Determine **isotope abundances** for light elements such as C, S, N, and O.

Decadal mission studies - Uranus Probe

3a. Determine **noble gas abundances & isotopic** ratios in planet's atmosphere

3b. Determine **atmospheric structure** at probe descent location.

9a. Determine **vertical profile of zonal winds** as function of depth in atmosphere

9b. Determine **presence of clouds** as a function of depth in atmosphere.

Venus Exploration Assessment Group - VEXAG

The VEXAG Goals, Objectives, and Investigations (GOI) further expands upon the PSDS Themes, Goals, and Priority Questions for Venus exploration.

The VEXAG GOI defines three specific goals for future Venus exploration:

Goal I Understand atmospheric formation, evolution, and climate history on Venus
Atmospheric Formation and Evolution

Goal II Determine the evolution of the surface and interior of Venus

Goal III Understand the nature of interior-surface-atmosphere interactions over time, including whether liquid water was ever present liquid water

https://www.lpi.usra.edu/vexag/reports/GOI-140625.pdf

Goal I Understand atmospheric formation, evolution, & climate history on Venus Atmospheric Formation and Evolution.

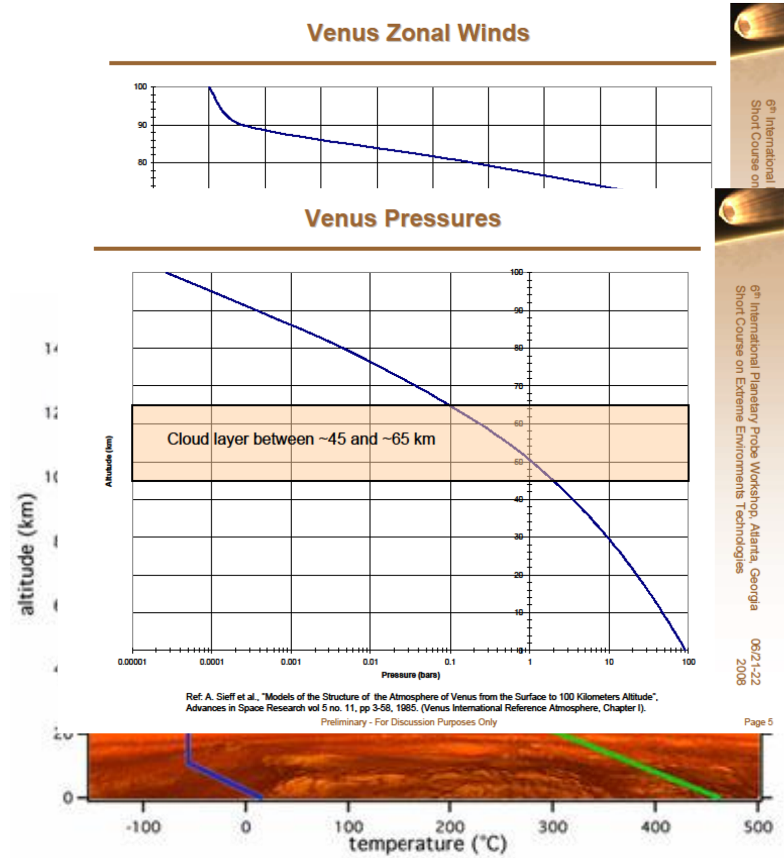
Objective: How did the atmosphere of Venus form and evolve?

Objective: What is the nature of the radiative and dynamical energy balance on Venus that defines the current climate? What processes control the atmospheric super-rotation and atmospheric greenhouse?

Objective: What are morphology, chemical makeup and variability of Venus clouds, what are cloud roles in atmospheric dynamical and radiative energy balance, and what is impact on Venus climate?

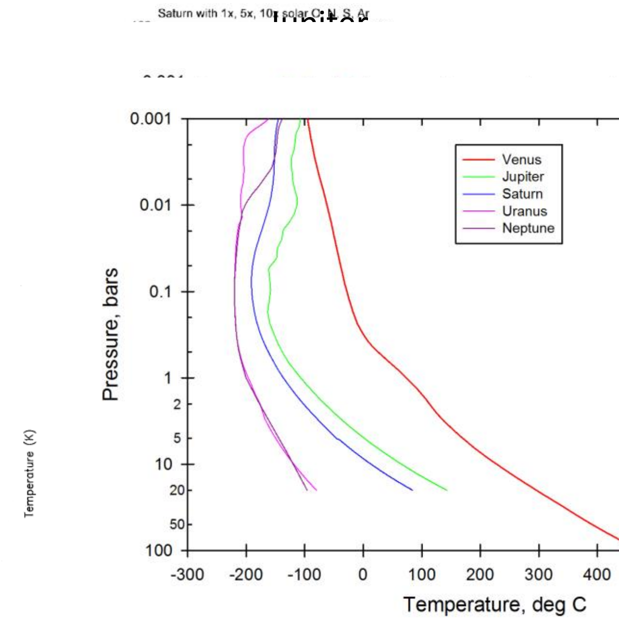
Altitudes of Interest - Venus

- To the surface!
- Three cloud layers, 65 km – 45 km
- Failure of all Pioneer Venus probes to measure temperatures below 12 km
- ~5-8 km: Atmospheric dynamics in “acceleration region”
- Atmospheric stability near the surface → strength of near-surface convection
- Surface outgassing and surface-interior interactions → Atmospheric composition, compositional gradients near surface



Altitudes of Interest – Giant Planets

- As deep as possible…!
- Descent science start near tropopause ~100 mb
- Noble gases: ~1-2 bars
- Cloud locations: depends on total abundances of N, S, and O
- Temperatures: tropopause / 20 bars
  Jupiter: 110K (-163C) / 415K (142C)
  Saturn: 82K (-191C) / 355K (82C)
  Uranus: 53K (-220C) / ~200 K (-73C)
  Neptune: 53K (-220C) / ~200 K (-73 C)



Note that the deep temperatures of Uranus and Neptune are not well constrained and depend on the static stability at the deeper levels.

Probe Science Instrument Payloads

Tier	Instrument	Measurement
Tier 1	Mass Spectrometer	Elemental and chemical composition, especially noble gases and key isotopes
	Atmospheric Structure Instrument (ASI)	Pressure and Temperature → Thermal Structure, Density, Stability Entry Accelerations → Density
Tier 2	Radio Science Experiment	Atmospheric dynamics: winds and waves; atmospheric absorption → composition
	Nephelometer	Cloud structure, aerosol number densities & characteristics
	Net Flux Radiometer	Net radiative fluxes: Thermal IR, solar visible

Target Specific Instruments

Venus

- Multispectral cameras for surface imaging, planetary context of landing site;
  Complement Doppler wind measurements in Planetary Boundary Layer
- Acoustic Instruments
  Speed of Sound → Composition or Temperature
  Microphone → Thunder (but more likely aeroacoustic noise), Surface winds

Giant Planets

- Helium Abundance Detector
- Acoustic Instruments / Speed of Sound
  → Composition or Temperature
  → Ortho/Para hydrogen ratio (esp. Ice Giants): Conversion may affect
    thermal structure, dynamics
    Thermal equilibrium reached slowly → measure convective upwelling
    from hot deeper atmosphere

SUMMARY

- Although each planet has individual science goals and priorities, there are common overarching science goals for all planetary atmospheres.
- Highest priority: Composition (esp. noble gases and key isotopes), thermal structure, and dynamics of deeper atmosphere
- Commonality of overarching science goals leads to certain common payload elements.
- How deep is deep? Depends on science goals, mission architecture, and planet.
- Most important: Noble gases can be reached in upper atmosphere.
- Temperatures extremes: very cold (~50K) to very hot (~735K at Venus surface)

Predecisional - For planning and discussion purposes only

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Extra Slides

Vision and Voyages: 2013-2022 Planetary Science Decadal Survey

Within each theme, entry probes at common probe targets required:

<u>Building New Worlds</u> addresses solar system formation and evolution, including

- How did gas giant planets Jupiter & Saturn and ice giant planets Uranus & Neptune and respective satellite systems accrete? Is there evidence of giant planet migration?

- What governed accretion, supply of water, chemistry, and internal differentiation of terrestrial planets? What roles did bombardment by large projectiles play in formation/evolution of terrestrial atmospheres, including Venus?

<u>Planetary Habitats</u> addresses planetary environments that could foster life, including

- Did terrestrial planets Mars or Venus host ancient aqueous environments conducive to early life? Is there evidence that life emerged?

Vision and Voyages: 2013-2022 Planetary Science Decadal Survey

Workings of the Solar System includes planetary atmospheres as records of volatile evolution of planets and interactions between surfaces, weather, and climate, including

- How do giant planets serve as laboratories to understand Earth, the solar system, and extrasolar planetary systems?
- Can understanding the roles of physics, chemistry, geology, and dynamics in driving atmospheres of giant planets and Venus lead to a better understanding of climate change on Earth?
- How have the myriad chemical and physical processes that shaped the solar system including Venus and the giant planets operated, interacted, and evolved over time?

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